HF antennas in theory and practice—a philosophical approach

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SINCE the antenna is such a vitally important component of any radio station, careful consideration of all the factors which govern its performance is essential when choosing one which will fulfil, as nearly as practically possible, one's individual requirements. In making a choice the following questions should be asked and the answers selected which are appropriate to one's requirements:

Q1. *What is my main interest in operating my station on the hf bands?*
A1.1. *Primarily dx chasing (including participation in contests) with a secondary interest in local QSOs—ie up to about 1,000km radius, or*
A1.2. *Primarily "local" QSOs (mainly in the 1·8, 3·5 and 7MHz bands) with a secondary interest in dx working.*
Q2. *What garden shape and space is available?*
A2. *A scale drawing with at least approximate indications of the main cardinal points.*
Q3. *What can I afford?*
A3. *If wire antennas are being considered, this is not important. However, if a commercially produced beam antenna (Yagi or quad) is desired this may be a most important factor. Especially if the purchase of a suitable tower and rotator system is contemplated.*

Whatever the answers to the above questions may be, it is important to realize that the predicted performance of any antenna assumes that it is functioning in *free-space above a perfectly conducting ground*. For virtually all amateur purposes it is reasonable to assume that these two criteria are never satisfied. Nevertheless, the *idealized* performance figures and polar diagrams of radiation—in both the azimuthal and zenithal planes—of various types of antennas may be studied in order to understand how any given type performs *in theory*. Indeed, it is useful to do so in order that the basic principles governing the performance of any particular type of antenna may be understood.

Theoretical considerations of antenna polar diagrams

Single-wire antennas

A vast amount of literature dealing with the theory of operation and performance of all types of antennas exists in the standard textbooks, in the many amateur radio magazine articles written on the subject, and in the numerous amateur radio handbooks and antenna handbooks available. While it is outside the scope of the present article to deal in detail with such a wide subject, the author desires to draw attention to some aspects of antenna performance that, it is felt, are often overlooked by many amateurs when they are trying to decide what is the best type of antenna for their requirements within the limits of area and height available.

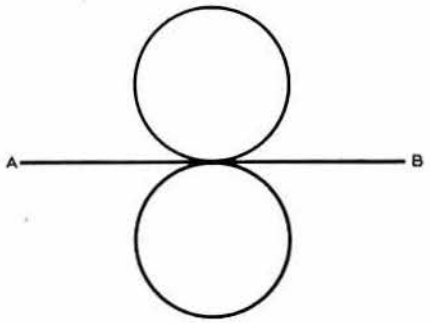

Fig 1. Typical single-plane representation of the polar diagram of a horizontal λ/2 dipole antenna. Line A B represents plane of the antenna

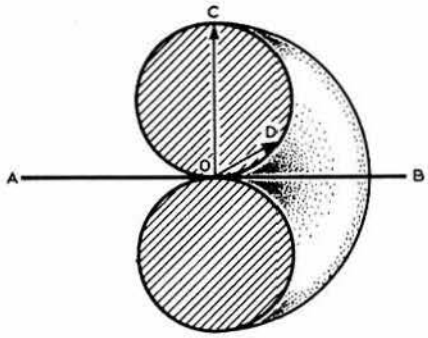

Fig 2. Section through solid polar diagram of a horizontal λ/2 dipole antenna. A B represents plane of the antenna

Polar diagrams—what do they mean? We are all familiar with the horizontal plane polar diagram of a typical horizontal λ/2 antenna (Fig 1) as shown in articles and textbooks. However, it is most important to understand that such a two-dimensional drawing is open to misinterpretation unless it is borne in mind that the radiation pattern is, in fact, *three-dimensional*. The easiest way to do this is to imagine this particular polar diagram to be approximately in the solid form of a doughnut, with the λ/2 horizontal antenna wire passing through the centre of its diameter and perpendicular to it. Fig 2 attempts to show such a "solid" polar diagram in section.

A study of this diagram will dispel a popular misconception that "there is no radiation off the ends of a horizontal λ/2 dipole". If the line A–B represents the antenna wire, then O–C represents the relative amplitude of radiated energy at right angles to the plane of the antenna, and O–D—though of a much smaller amplitude—represents radiation at a quite small angle to the axis of the antenna. In other words, it clearly indicates that *some* radiation takes place virtually "off the ends" of the wire. Now, if one imagines that Fig 2 represents a section through the "doughnut" solid polar diagram in the *vertical* plane, it will be seen that O–D represents radiation off the ends of the antenna *at a very low zenithal angle*. For dx working such low angle radiation is just what is needed and, although this will be of considerably lower amplitude than that taking place at right-angles to the plane of the antenna at a similar zenithal angle, under reasonably good propagation conditions it can be very effective.

This same reasoning and conception of a solid polar diagram equally applies to long-wire antennas embodying a number of out-of-phase half-waves at the operating frequency being considered. The number of "lobes" of radiation produced by such antennas is equal to the number of half-wavelengths of wire comprising the particular antenna. Bearing in mind that, just as in the case of the simple λ/2 antenna, the polar diagram of a long-wire antenna is a solid, three-dimensional figure, it will be evident that, quite apart from the radiation which takes place in the direction of the "main" angle of each lobe of radiation, an appreciable

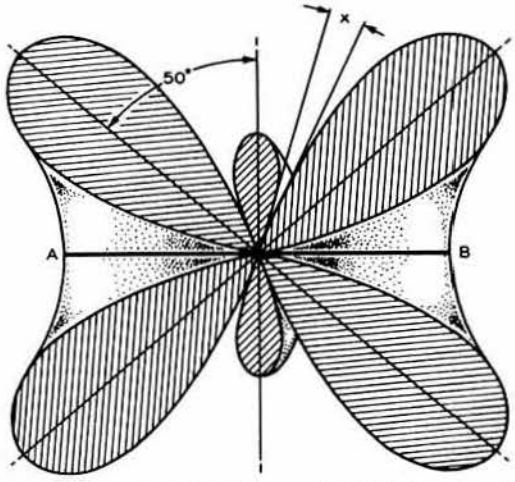

Fig 3. Section through solid polar diagram of a 3λ/2 horizontal antenna. A B represents the plane of the antenna

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amount of low-angle radiation will also take place in line with the axis of the long-wire antenna.

Fig 3 represents a section through the solid polar diagram of a 3λ/2 long-wire antenna. It will be seen that around the centre of the antenna there is a radiation pattern in the form of a "flattened doughnut" while the other two lobes are in the form of hollow "rounded" cones. The angle between a line drawn through the "doughnut" at an angle of 90° to the plane of the antenna wire and a line drawn from the centre of the antenna along the major chord of each of these cones is approximately 50°, and the angle between the plane of the antenna and the major chord of a major lobe is therefore about 40°.

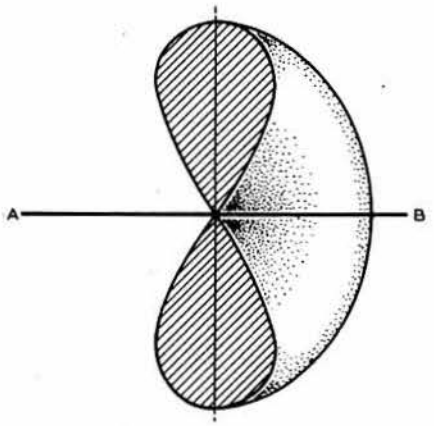

Fig 4. Section through solid polar diagram of a two λ/2 in-phase horizontal antenna. A B represents plane of antenna.

It is important to note that, as distinct from the radiation pattern of a λ/2 antenna where most of the energy is radiated at high zenithal angles, the greater part of the radiated energy from a long-wire antenna takes place at much lower angles. This means, of course, that such long-wire antennas are more effective than a λ/2 antenna for dx working where a zenithal angle of radiation of something between 5° and 15° is desirable.

In the case of a horizontal antenna comprising two or more half-waves fed *in phase*, a multiple lobe pattern is not formed but the typical λ/2 "doughnut" radiation pattern is considerably sharpened so that, for example, the pattern of two half-waves fed in phase will approximate in shape to the "flattened doughnut" shown in Fig 4 about the centre of the antenna, and all the energy supplied to the antenna will now be concentrated in the "doughnut". For illustrations of the theoretical radiation patterns (both in the horizontal and vertical planes) of hf antennas, including information on the gain of long-wire antennas up to, say, five wavelengths long, the reader is referred to the *Radio Communication Handbook*, 5th edition, Vol 2, Chapter 12, and the ARRL *Antenna Handbook*.

It should be noted that, for a given amount of energy fed to the antenna, whereas a dipole "doughnut" radiation pattern distributes this energy in a virtually "all-round" or quasi omni-directional form, the pattern of a 3λ/2 long-wire antenna has four quite sharp nulls, approximately indicated in Fig 3 by the sample null angle "x". The energy that would have been used to fill these nulls, had the radiation pattern been that of a λ/2 dipole, now forms part of the energy contained in the major lobes. This results in some gain over a λ/2 dipole in the directions of the main angles of radiation of these lobes. However, with a 3λ/2 antenna this gain is only about 1dB per major lobe. It is not until a long-wire is about four to five *wavelengths* long that the gain in the directions of the major chords in the major lobes rises to about 3 or 4dB over a dipole.

Wire and tubular element beams

The theoretical gain and front-to-back ratio of any particular beam antenna may be found in articles and text books on the subject. In general it may be said that, apart from these two features, any form of beam antenna tends to produce its main radiation of energy at considerably lower zenithal angles than a simple single-wire antenna, and this is a considerable advantage for dx working. It is also possible to achieve propagation at low zenithal angles by "stacking" dipoles or beam antennas vertically, one over the other, separated by half a wavelength at the operating frequency and fed in phase. However, except for operation on the 28MHz and perhaps the 21MHz band, the space and mast height required for such an arrangement is out of the question for most of us.

For an explanation of how polar diagrams are constructed and for much other helpful information on the theory of operation of many kinds of antennas, the reader is again referred to *Radio Communication Handbook*, Chapter 12.

Practical considerations

In all the foregoing it has been assumed that any particular antenna under discussion is located in free space above a perfectly conducting earth, and is free from the effects of relatively nearby conducting and reflecting objects such as buildings, trees, metal masts or towers, wire fences etc. In practice, in the typical case of an amateur installation, this ideal situation is never, or hardly ever, possible to attain. We must, therefore, recognize that the actual performance of any type of antenna located in a typical back garden will be more or less different from the theoretical performance according to the local circumstances which affect its operation. However, given a height of at least λ/2 above a ground of average conductivity and a reasonably unobstructed location, the actual performance will be fairly close to its theoretical performance.

Nevertheless, it is unlikely that many amateurs will be able to erect horizontal antennas of any type at λ/2 above ground for any frequency band below 14MHz. This constraint on dx performance on 7MHz may be overcome by using a vertical λ/4 antenna (typically a λ/4 ground plane) at this frequency. Assuming that the base of such a gp antenna is supported at about 3m above ground—so as to accommodate the usual four gp wire radials at a suitable zenithal angle and to provide a feedpoint impedance of between 35 and 50Ω—and with the approximately 10m vertical λ/4 radiator mounted on a 3m mast, the total height of the structure will be about 13m. Although it is true that the total height may be reduced by, say, 2m or so by the use of top capacity loading, it will still represent about the maximum that most amateurs could contemplate. Such a construction scaled up in dimensions for 3·5MHz operation is clearly out of the question for all except a tiny minority.

A practical and effective alternative for these two bands is the vertical multiband trap λ/4 antenna, either mounted with its base at ground level and worked against a really effective earth system, or raised up above ground level to a height sufficient to accommodate a gp system. Alternatively a 20·7m (approximately 68ft) end-fed wire could be used in conjunction with a suitable atu as a λ/2 voltage-fed antenna on the 7MHz band and as a λ/4 current-fed antenna on 3·5MHz. In the latter case the antenna would require an atu in the form of a series-tuned LC circuit connected to a good earth system or counterpoise wire.

For the 1·8MHz band few amateurs can hope to erect anything larger than a λ/4 or λ/2 end-fed wire or a centre-fed 3·5 to 28MHz multiband dipole (either trap type or the G5RV) used with the station end of its feeder (whether balanced open-wire, twin-lead or coaxial) shorted, and worked in conjunction with a good earth system or a counterpoise wire and a suitable series-tuned LC circuit atu. A centre-fed antenna used in this way functions as a "Marconi" or "T" antenna and can be surprisingly effective on 1·8MHz, especially if supported at a height of 12m or more.

Antennas for limited space

Despite the desiderata imposed by theory, it is remarkable what liberties can be taken with the geometry of single-wire antennas while still obtaining a satisfactory performance. Provided that an antenna is supported as high as is practicable above the ground, is located as far from local obstructions (particularly metallic ones) as possible, and is well insulated from its supporting structures, it can be bent or partly folded to suit the space available and yet give surprisingly good results. This is not so, of course, for multiwire beam antennas such as the rhombic or V-beam types, the performance of which depends upon the correct spacing, wire length, and the included angles between the wire elements in order to obtain the correct phase relationships between such wire elements to produce the required beam effect. However, many designs for "compact" or "miniature" beams of Yagi or quad type exist and are capable of providing quite good results.

Where it is possible to use one central supporting mast of reasonable height (say 10m or more) but the length of the space available for the antenna is limited, the inverted-V dipole antenna may be used and is capable of excellent results. Such an antenna may be a simple λ/2 wire, centre-fed, for one band only, or may consist of a trap dipole or a G5RV for multiband operation. Although it is desirable that the included angle between the two halves of an inverted-V dipole antenna at its apex should be about 130° to 140° for optimum performance, such an arrangement only results in a relatively small saving of overall length at ground level required for its installation.

Fig 5 shows, to scale, three arrangements of a 3·5MHz band inverted-V dipole antenna. Antennas "A" and "C" are supported at the centre by a 10m mast, and antenna "B" by a 14m mast. Assuming that the outer ends of each of these dipoles are supported about 3m above ground using a 1m length of nylon rope between each end-insulator and each end-support post, it will be seen that a total garden length of about 37m (120ft) will be

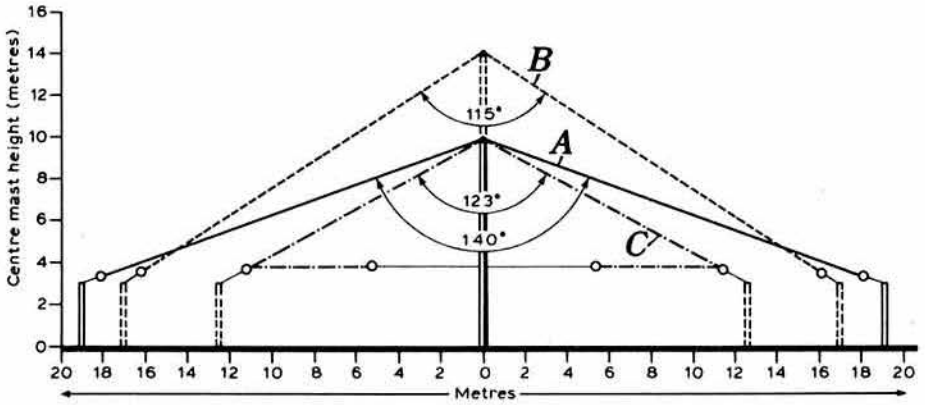

Fig 5. Three possible arrangements of an inverted-V dipole for 3,650kHz. For clarity the centre feeder is not shown

required for antenna "A" but only 34m (112ft) for antenna "B"—if the dipole had been supported at each end by a 10m mast and the same lengths of nylon rope, the masts would have been about 41m (134ft) apart. However, the 14m (46ft) mast of antenna "B" is getting close to the limits of practicality for most amateurs.

It is unfortunate that most of the drawings of inverted-V dipoles appearing in articles or handbooks have not been to scale, so that the mast height requirements have not been readily apparent. However, since most of the useful radiation from a $\lambda/2$ antenna takes place from, approximately, two-thirds of its total length equally disposed about its centre, this means that one-sixth of its physical length at each end may be folded up to save space without noticeable detriment to its radiation efficiency. Antenna "C" in Fig 5 is constructed in this way and, while requiring only a 10m centre mast, permits an included apex angle of 123° and occupies a ground length of only 25m (82ft). On each side of the dipole a length of about 6·5m (21·3ft) is folded in towards the centre support mast and attached to it by suitable lengths of nylon rope.

Similar "liberties" may be taken with dipole or long-wire antennas for the higher frequency bands 7 to 28MHz. In the case of horizontal antennas, up to one-sixth of the antenna length at each end may be folded back or allowed to hang vertically (or at a convenient angle to the horizontal top portion). □

A simple and sensitive field strength meter

by J. M. NOEDING, LA8AK*

IN addition to being a sensitive field strength meter, the device to be described can also be used for (a) unknown frequency tracing, (b) for hf and i.f. amplifier tuning, (c) for balanced modulator carrier suppression adjustments, (d) for spurious tests, (e) as an hf selective voltmeter, and much more. The sensitivity is good, and much better than the passive circuits usually described for such purposes, see Table 1.

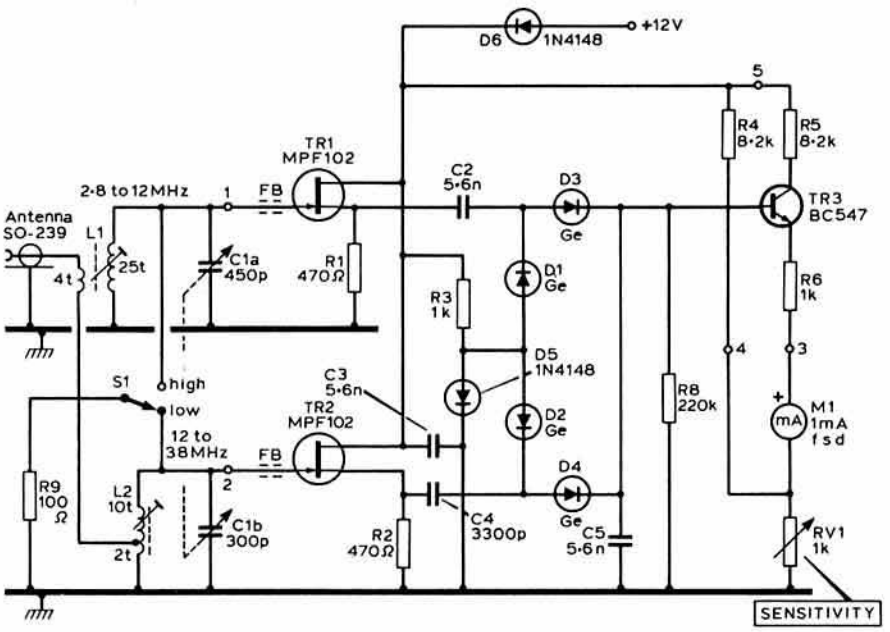

Fig 1. Circuit diagram

Construction

The mechanical construction is shown in Fig 2; the aim being to construct an instrument which would be easy to copy. The transistors and their related components are mounted on a pcb. Most parts can be obtained through "surplus" suppliers, which may mean that larger than usual components may be used.

Two selective amplifiers are used, but it is possible to use one and switch between two tuned circuits—a form of construction which the author found easier to use. The amplifiers are almost unique, comprising a rarely-used configuration, which has been described once before in *Technical Topics*. The tuned circuit provides the only voltage gain, and the transistors are used only as a voltage-follower (source follower). Thus the amplifiers are unconditionally stable, and will not cause any problems except at very high LC ratios where the circuit may act as a Colpitts oscillator when the "source" is capacitively loaded.

No input switching is used, as the tuned circuits are fed in series. The opposite tuned circuit to the band in use is damped with a 100Ω resistor, thus eliminating false resonances.

Coils

The constructor may have some difficulty with these, but the easiest method is to wind the coil and then connect a 400pF (250pF) capacitor and "dip" it at 3.5MHz (14MHz). Then remove or add turn's until the required frequency can be adjusted by the slug. Count the turns and make a tapping at approximately 15–20 per cent.

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